XIPHOSURID BURROWS FROM THE LOWER COAL MEASURES (WESTPHALIAN A) OF WEST YORKSHIRE

by J. I. CHISHOLM

ABSTRACT. Bilobate burrows lying parallel to bedding are described from a shallow-water sandstone. The burrows are linked to structures produced by oblique movement through the sediment, the outlines of these suggesting that the animal responsible was a xiphosurid, perhaps *Bellinurus*. The internal structure of the burrows shows transverse markings on either side of a median furrow but the external surfaces are poorly preserved and it is uncertain to which of the existing bilobate ichnogenera the trace fossil belongs. It is provisionally referred to *Aulichnites* Fenton and Fenton, 1937 as *Aulichnites*? *bradfordensis* ichnosp. nov.

TRACE fossils attributed to limulid movements are known from many parts of the geological column but the majority of those described are walking (or half-swimming) traces (*Kouphichnium* Nopsca; *see* Häntzschel 1975, p. W75), or are resting traces (*Limulicubichnus* Miller, 1982). Records of these in the Silesian rocks of the central Pennines are summarized by Eagar *et al.* (1985). Limulid burrowing traces have been described less commonly, which is surprising in view of the known burrowing habits of Recent *Limulus*; the structures described here are thought to have been produced by this process.

GEOLOGICAL SETTING

The trace fossils were found at Bolton Wood Quarries (British National Grid Reference SE 162 366) in Bradford, West Yorkshire. Some of the burrows were found in place, distributed sparsely through some 1·2 m of fine-grained sandstone exposed in the north-western part of the quarry but the best-preserved material, including the holotype, was found in slabs lying loose at the foot of this face.

The following section was visible in 1983:

Top of section at SE 1627 3660	thickness (metres)
8. Coal, interlaminated with black mudstone.	0–0·05
7. Alternations of grey striped siltstone and ripple-laminated sandstone; rooty top.	4·80
6. Sandstone, fine and very fine-grained, mainly trough cross-bedded in sets up to about 1·0 m thick, with palaeocurrent flow to east-south-east; some mudstone clasts and tree trunks; some ripple- and parallel-laminated bands. Uneven crosive base.	13·50
5. Siltstone, striped, draped over eroded surface of bed below.	0–0·20
4. Sandstone, fine and very fine-grained, with low-angle wedge-bedding; *Arenicolites carbonarius* (Binney) sparsely present in top few cm of some beds.	1·70
3. Siltstone, striped, argillaceous.	3·90
2. Sandstone, fine and very fine-grained, with low-angle wedge bedding.	1·80
1. Sandstone, fine and very fine-grained; ripple lamination and parallel lamination alternating in bands 0·06 to 2·26 m thick; parting lineation and rib and furrow structures indicate consistent palaeocurrent flow to west; *Aulichnites*? *bradfordensis* ichnosp. nov. sparsely distributed through the top 1·20 m.	7·00

Base of section at SE 1605 3643.

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The section is similar to one recorded at the quarries by Stephens *et al.* (1953, pp. 84–85). These authors identified the sandstone (beds 1–6 of the section detailed above) as the Gaisby Rock, which was formerly quarried at Gaisby, some 500 m to the north-west of Bolton Wood Quarries. They regarded the Gaisby Rock (*ibid.*, pp. 75–76) as a locally thickened representative of a thin sandstone known in the Bradford area as the 80-Yard Rock, but a more likely correlation has been put forward by C. G. Godwin (pers. comm.). He points out that the Gaisby Rock is about the same thickness as the 'main lower leaf' of the Elland Flags (terms defined by Godwin 1984, fig. 1), and in the absence of indications to the contrary, he prefers to correlate the two, as no local variations in thickness are thereby implied. This correlation is accepted here, with the implication that the Gaisby Rock lies about 30 m higher in the sequence than is indicated by Stephens *et al.* (1953, p. 70). On either correlation, the section lies within the lower half of Westphalian A.

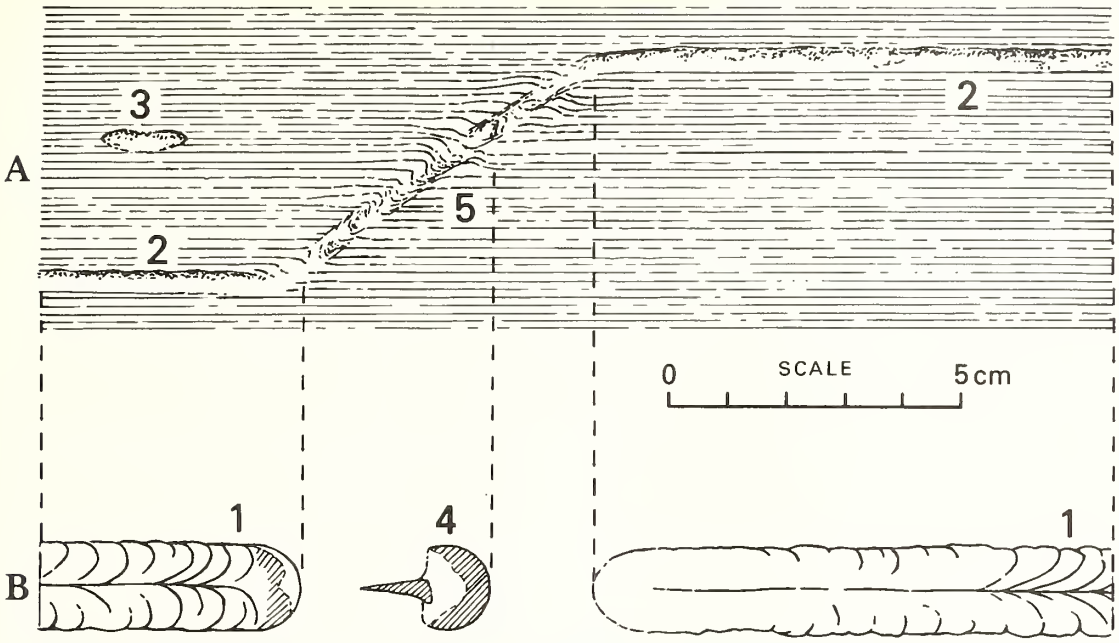
The Coal Measures of the Pennine region are of fluvial or fluvio-deltaic origin (Elliott 1969; Haszeldine and Anderton 1980) and in this context bed 6, the thick, cross-bedded sandstone with tree trunks and mudstone pebbles, is likely to represent a river or distributary channel deposit. The origin of beds 1–5 is less certain, though their position beneath the channel deposit suggests that they may represent a set of crevasse-splay, mouth-bar and barrier-beach sediments. Whether all of these environments are present here, or only some of them, cannot be determined from the limited exposures available. The presence of *Arenicolites carbonarius* suggests that the environment was non-marine (Hardy 1970*b*, p. 9).

DESCRIPTION OF TRACE FOSSILS

Most of the specimens were collected from the top few centimetres of a loose slab measuring about 6 square metres in surface area. Others were obtained from smaller slabs. The traces were also found in place but only a few of these could be collected, due to the hardness of the rock. The way-up of the loose material was determined by comparison with that obtained *in situ*. All the traces are full reliefs (endichnia), preserved entirely within the sandstone; there are no epireliefs or hyporeliefs. Cut sections suggest that all were produced within the sediment and that no traces formed at the sediment/water interface have been preserved. The structures are of two kinds, about equal in abundance, with a few connected examples that prove their common origin; they are distinguished as 'oblique penetration structures' and 'horizontal burrows'. An idealized reconstruction of the trace fossils is shown in Text-fig. 1.

Oblique penetration structures. These are bedding disturbances, irregularly shaped or roughly quadrangular as seen from above (Pl. 75, figs. 3, 5, 10; Pl. 76, figs. 1, 3) and measuring 10–25 mm in width by 10–35 mm in length. The average width (22 examples) is 15 mm. A section cut across the width of one example (Pl. 75, fig. 6) shows irregular distortion of dark bedding-laminae within an ill-defined biconvex area of disturbance. Side views (Pl. 75, figs. 1, 2, 4, 9) show that most of the disturbances extend obliquely through the sediment at angles of about 35° from the horizontal; a few are steeper. The greatest thickness of sediment penetrated in this way is 30 mm, but the specimen concerned is incomplete both at top and base. When a specimen is split along the bedding, roughly similar quadrangular shapes appear at all levels in the structure. In two of the specimens (Pl. 75, figs. 3, 5) the outline is hoof-shaped or lunate with a pointed projection at the centre of the concave side: strong evidence for a xiphosurid origin. In one of these specimens the lamination bulges upwards at the convex (head) end and downwards at the pointed (tail) end, but in the other is depressed throughout. A few other specimens show signs of the 'xiphosurid' shape, the asymmetry of which enables the forward end to be distinguished from the rear. Cut sections of these oriented examples show that more of them were formed by upward movement through the sand than by downward movement.

Horizontal burrows. The burrows are ribbon-like structures, flattened parallel to the bedding. They are straight or variably curved, and incomplete lengths up to 250 mm are present. In width they range



TEXT-FIG. 1. Idealized diagram to show structure of *Aulichnites*? *bradfordensis* in side view (A) and on bedding planes viewed from above (B). Movement of animal from left to right. Horizontal burrows are shown on bedding planes (1), in lengthwise section (2), and in cross-section (3). Oblique upward penetration structure shown on bedding (4) and in lengthwise section (5).

from 10 to 19 mm, the majority being about 15 mm across, and the thickness of most examples lies between 2 and 4 mm; a single specimen is 7 mm thick. The more complete burrows pass at one or both ends into oblique penetration structures and the outline of these can be used (as described above) to determine the direction of movement. The anterior end in such cases tends to have a sharp, convex outline whereas the posterior end is more vague (Pl. 75, figs. 7, 8; Pl. 76, figs. 1, 5).

The outer surfaces of the burrows do not separate cleanly from the matrix and so cannot be observed directly; all the specimens have split through the middle, revealing the internal structure. Cross-sections suggest that both the upper and lower surfaces are generally ill defined, but that the upper are in some cases vaguely bilobate, with a faint median furrow, whereas the lower tend to be flat or unilobate. The sediment inside the burrows shows a disturbed texture in which dark flaky grains of mica and carbon have been reoriented from their original position parallel to bedding, and have also been concentrated at the top of the burrow (Pl. 76, fig. 2). In many specimens the disturbed material, as seen on bedding surfaces, shows a bilobate pattern, with a well-marked median groove and less regular lateral grooves (Pl. 76, figs. 1, 3, 4). Transverse markings, often arranged in a chevron pattern, are present in parts of some specimens (Pl. 76, figs. 1, 3); in the best preserved examples the chevrons open towards the anterior (Pl. 76, fig. 1). In one specimen (GSL 1839) the transverse lines are seen to mark the ends of faint laminae in the burrow fill, but details of this texture are not clear.

INTERPRETATION OF TRACE FOSSILS

The hoof-shaped outlines of some of the penetration structures (Pl. 75, figs. 3, 5) compare well with the shapes produced in soft sediment by juveniles of the Recent horseshoe crab, *Limulus polyphemus* (Caster 1938, pl. 12; Miller 1982, fig. 3), and are good evidence for the xiphosurid origin of the whole burrow assemblage. Burrowing is a normal activity of *L. polyphemus* (Caster 1938,

pp. 17–19; Vosatka 1970) and is thought to have been a characteristic feature of xiphosurid behaviour since Ordovician times (Bergström 1975, p. 301). The initial burrowing movements of juvenile *L. polyphemus* have been described by Vosatka (1970, p. 283) and by Eldredge (1970). The sediment is excavated and displaced by the limbs while the prosoma is pushed forwards and downwards into the sediment by flexing movements of the body. The processes involved in continuous burrowing have not been described in detail, however, but are supposed by Caster (1938, p. 19) to involve a combination of leg and tail movements with the ploughing action of the headshield. The deformation produced in the sediment by burrowing was not described by any of these authors, so that the interpretation of the Bradford burrows is necessarily conjectural.

The median groove of the burrow-fill was probably made by the telson, the straightness of the groove indicating that it did not lash from side to side during burrowing but probably was pressed downwards against the sediment or trailed passively. The internal structure of the burrows is interpreted as a back-fill texture. It roughly reflects the outline of the rear of the animal (Pl. 75, fig. 7; Pl. 76, fig. 1), so was probably produced by repeated backward pressure against the sediment that had been displaced and passed back under the animal by the action of the limbs. The marginal furrows were probably produced by the outer margins of the prosoma and the average width of the burrows, 15 mm, is therefore a measure of the width of this feature.

The penetration structures are not regarded as escape-traces from rapid sedimentation or erosion, because rising and descending structures are present in the same few centimetres of sandstone; it is more likely that oblique movements were part of normal burrowing behaviour. This conclusion is consistent with the lack of any preferred orientation of burrows or penetration structures relative to the current direction shown by parting lineation (Pl. 76, fig. 1) and ripple lamination. The assemblage is thought more likely to have resulted from scavenging for food than from concealment or resting, these types of behaviour being more probably represented by the closely related trace fossil *Limulicubichnus rossendalensis* (Hardy, 1970).

Of the two genera of xiphosurids known to occur in Upper Carboniferous sediments of the region, *Bellinurus* and *Euproops* (Calver 1968, pp. 159–160), the former is thought to have lived in open-water habitats, whereas the latter probably lived in the coal swamps (van der Heide 1951, pp. 63–65); *E. danae* may even have been able to live on subaerial vegetation (Fisher 1979). *Bellinurus* is thus more likely to have produced the burrows described here, which occur in fluvial crevasse-splay or delta-front sandstones.

DISCUSSION

Burrows that can be regarded as incomplete examples of *Aulichnites? bradfordensis* have been found at other localities in the Upper Carboniferous of the Pennine region. One specimen (British Geological Survey, Palaeontology Collection, Keyworth, JIC 1259–60) was found by the author in loose blocks of fine-grained, micaceous, parallel-laminated sandstone at Catlow Quarry, Lancashire (grid reference SD 8873 3676). The quarry is in the Dyneley Knoll Flags (Earp *et al.* 1961, p. 137), which lie at about the same stratigraphical level as the Elland Flags (Wray 1929, p. 272). The burrow

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EXPLANATION OF PLATE 75

Figs. 1–10. *Aulichnites? bradfordensis*, ichnosp. nov. 1, 2, 4, 9. Oblique penetration structures, vertical sections cut parallel to direction to travel; note variable nature of lamination disturbance but consistency of angle at which sediment was penetrated. British Geological Survey, Palaeontology Collection, Keyworth: GSL 1844, 1845[A], 1845, 1836, all ×2. 3 and 5. Oblique penetration structures showing 'xiphosurid' outline; view from above, light from top left. 3, paratype, GSL 1832, ×2; 5, GSL 1846, ×1. 6. Oblique penetration structure, section across width. GSL 1843[A], ×2. 7 and 8. Horizontal burrows, view from above, light from top centre. Bilobate pattern; 'head' at right. 7, GSL 1834, ×1; 8. GSL 1830, ×1 (*in situ* specimen). 10. Oblique penetration structure, view from above, light from top left. GSL 1842, ×1.

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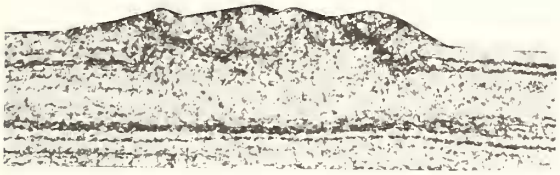

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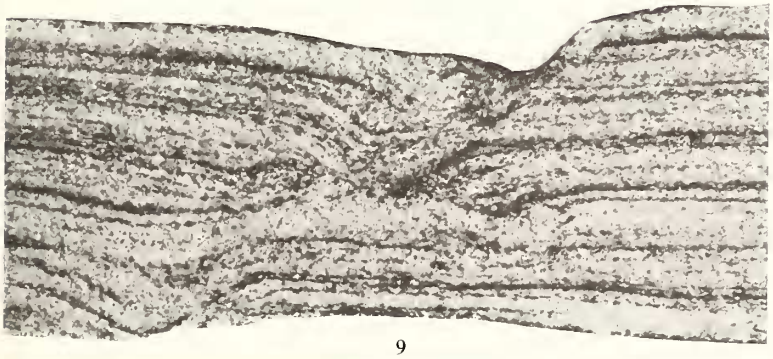

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CHISHOLM, *Aulichnites*? *bradfordensis*

is preserved on a bedding plane as an internal section 12 mm broad by 60 mm long, with a well-marked median furrow but only faint transverse markings. The anterior end has a sharp semi-circular outline, whereas the posterior end fades off more gradually. *L. rossendalensis* is common as hypichnial mounds on blocks in the same quarry. Another example (University of Manchester, Department of Geology Collection, MGSF 95), collected by Dr J. E. Pollard from the Milnrow Sandstone (equivalent of the 80-Yard Rock) at Sycamore Quarry, Kerridge, Cheshire (SJ 940 766), is about 22 mm wide, with curved transverse chevron markings and a median furrow, and follows a gently curved course, with one sharper bend, for a distance of about 30 cm. The traces described from sandy siltstones above the Butterly Marine Band at Standedge, West Yorkshire, by Eagar *et al.* (1983, p. 298) under the provisional name '*Scolicia*', are also similar in many ways to *A.*? *bradfordensis*, being endichnial burrows flattened parallel to bedding, with bilobate structure and a pattern of transverse markings in places. The maximum width of the burrows is about the same as that of the Bradford traces, but no 'xiphosurid' outlines are associated. The Standedge traces are somewhat older (Kinderscoutian) than those from Bradford but they likewise occur in sediments laid down in a river mouth or interdistributary bay environment (Eagar *et al.* 1983, pp. 287–288). They are thought to have been produced by small arthropods which, in view of the similarities with *A.*? *bradfordensis*, may well have been xiphosurids. Some bilobed traces from the Grassington Grit (Pendleian) of West Yorkshire were referred by Eagar *et al.* (1985, pl. 1E, F) to cf. *Aulichnites*. They are more sinuous than any so far mentioned and more closely resemble *A. parkerensis*; they appear to be burrows but their greater sinuosity suggests that they were made by a different arthropod.

Three different aspects of xiphosurid behaviour have now been identified as trace fossils in Upper Carboniferous sediments of the Pennine region. Resting, alternating with short forward movements, is represented by *L. rossendalensis* (Hardy 1970*a*, *b*), walking and half-swimming movements by *Kouphichnium* aff. *variabilis* (Chisholm 1983), and burrowing movements by *A.*? *bradfordensis*. The outlines of *L. rossendalensis* and *A.*? *bradfordensis* are very similar in shape and size, suggesting that they were made by the same animal. All the traces were probably produced by members of the genus *Bellinurus* (Hardy 1970*a*; Chisholm 1983; and above). Bilobate burrows showing a more sinuous pattern may have been produced by other arthropods.

SYSTEMATIC PALAEONTOLOGY

Ichnogenus AULICHNITES Fenton and Fenton, 1937

Remarks. The type species, *A. parkerensis* Fenton and Fenton, 1937, is a bilobate burrow consisting of an epichnial ridge 5 to 11·4 mm wide with a strong median furrow. The burrow filling is of sand in oval layers which are concave anteriorly and convex upwards (Fenton and Fenton 1937, pp. 1079–1080). An examination of the holotype by Hakes (1977, p. 218) has shown that the undersurface is unilobate and convex downwards, the depth below the median furrow being about 3 mm.

EXPLANATION OF PLATE 76

Figs. 1–5. *Aulichnites*? *bradfordensis*, ichnosp. nov. 1. Horizontal burrow; 'head' at right, chevron ornament at left. Penetration structures and a second burrow also visible. View from above, light from top centre. Holotype, GSL 1831, × ½. 2. Horizontal burrow, side view of lengthwise section showing disturbed texture and local concentration of dark material towards top. Undisturbed lamination in lower half of specimen. GSL 1837, × 2. 3. Horizontal burrow showing bilobate structure and ornament; penetration structures also present. View from above, light from top centre. Paratype, GSL 1833, × ½. 4. Horizontal burrow showing irregular bilobate pattern. View from below, light from left. GSL 1835, × ½. 5. Horizontal burrow with sinuous shape; 'head' end at right. View from below, light from top centre. Paratype, GSL 1832, × 1.

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CHISHOLM, *Aulichnites? bradfordensis*

Aulichnites? bradfordensis ichnosp. nov.

Plates 75 and 76; text-fig. 1

1976 ?*Gyrochorte*, Hakes, p. 26; pl. 5, fig. 4.
1977 ?*Aulichnites* sp., Hakes, p. 218; pl. 1*b*.
1983 '*Scolicia*', Eagar *et al.*, p. 298; pl. 24A–C.

Derivation of name. From the city of Bradford, where the trace fossils were found.

Holotype. British Geological Survey, Palaeontology Collection, Keyworth, Nottingham, GSL 1831.

Paratypes. GSL 1832–1834.

Type locality. Bolton Wood Quarries, Bradford, Yorkshire.

Horizon. Gaisby Rock (but see above); age Westphalian A.

Occurrence. Sparsely in fine-grained sandstone, about 22 m below top of Gaisby Rock.

Diagnosis. Horizontal bilobate burrows linked to obliquely rising or descending traces, some of which have a hoof-shaped outline in plan view. The bilobate burrows are straight or variously curved with a median furrow and variable transverse markings, chevron-shaped in places. The width is generally about 15 mm.

Description. A detailed description of the two main elements, oblique penetration structures and horizontal burrows, is given on pp. 620–621.

Remarks. The 'xiphosurid' outline of the best-preserved penetration structures (Pl. 75, figs. 3, 5) closely resembles, both in size and shape, that of the resting trace *L. rossendalensis* described by Hardy (1970*a*) from an Upper Carboniferous sandstone in Lancashire, but it would be inappropriate to apply this name to the Bradford structures since these are extensive burrow systems, not short resting traces.

All burrows collected are full-reliefs made up of material disturbed by the passage of the animal. The majority are preserved on parting surfaces parallel to bedding as upwardly convex bilobate ridges and show internal structure rather than the ornament of the top surface. Most bilobate ichnogenera are based on material preserved as epireliefs or hyporeliefs rather than as full-reliefs, so the choice of a suitable name is not straightforward; however, the evidence of cross-sections shows that the structures are closer to epireliefs than to hyporeliefs, in that the upper surfaces are in places convex and vaguely bilobate, whereas the lower surfaces are poorly defined and appear to be unilobate or flat. Of the bilobate epirelief ichnogenera *Halopoa*, *Scolicia*, *Gyrochorte*, and *Aulichnites*, the first is considered unsuitable because it has an irregular surface ornament, not notably transverse, and is only bilobate in places (Martinsson 1965, figs. 29–32). The name '*Scolicia*' has been used for trails or burrows of a broadly similar nature from Upper Carboniferous sandstones elsewhere in the Pennine region (Eagar *et al.* 1983, p. 298), but is not used here because most examples of *Scolicia* (and its synonyms) illustrated by Häntzschel (1975, p. W107) show surface patterns or internal structures more complex than those of the Bradford burrows. *Gyrochorte* has a simple, plaited pattern on the bilobate upper surface but the depth of the structure can be greater than its width and Heinberg (1973) has suggested that the trace was made by a worm-like animal burrowing obliquely through the sediment. Because of these differences of structure and interpretation, *Gyrochorte* is considered less appropriate than *Aulichnites*, an ichnogenus with a similar surface pattern but in which the width of the burrow is greater than the depth (Fenton and Fenton 1937, pl. 1, fig. 1; Hakes 1977, p. 218).

The new trace fossil is only tentatively assigned to *Aulichnites* in view of the uncertain nature of the outer surfaces, which in the type ichnospecies, *A. parkerensis*, are bilobate above and unilobate below (Hakes 1977, p. 218). These uncertainties apart, it is clearly different from *A. parkerensis* in several notable respects. First, it is linked to hoof-shaped structures; secondly, the pattern of transverse

markings is much less regular, and less consistently present, than in *A. parkerensis*; thirdly, where the transverse markings are chevron-shaped these open towards the anterior rather than to the posterior; and fourthly, the chevrons meet the centre line at a more acute angle.

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